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Review

Tactile sensing in human–computer interfaces: The inclusion of pressure sensitivity as a third dimension of user input

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ABSTRACT

This paper presents a review of tactile technologies for human–computer interactivity via touch interfaces, where touch force is measured as a third dimension of user input along with touch location. Until recently, tactile technologies for computing applications have detected only the location of a touch (or several touches simultaneously) with no additional information about the force or pressure the user imparts to the interface. Such additional input may open up new applications in force-enhanced gestures, for example the touch force may dictate the linewidth used in drawing software, or the speed of a scroll gesture may be increased with increasing applied force. Here we review the underlying physical principles behind several force sensitive touch technologies. The latest innovations by leading technology developers, only available in the patent literature, are also described and where public data exist the force-resistance behaviours of several key technologies are compared in terms of their sensitivity and range of response. The advantages and disadvantages of each technology are discussed, along with the current and possible future applications in consumer electronics. It is shown that the concept of pressure-sensitivity as an additional user input mechanism is fast gaining traction, with many implementations already found in commercial products. Furthermore, a study of the patent trends shows that this functionality may soon become commonplace in the new generation of consumer electronic devices.

Contents

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1. Introduction

Tactile sensing has become increasingly important in human–computer interactions (HCI), introducing novel and intuitive ways for the user to interact with a computer interface, such as in machinery control panels, point-of-information (POI) and point-of-sales (POS) kiosks, and device interfaces in consumer electronics. Touch may be detected on an integrated trackpad (such as in a laptop) or on a transparent touchscreen overlaid onto the display (for example in smartphones and tablets), thus eliminating the need for a separate touch interface as the user can directly interact with the icons shown on the underlying display.

Currently most touch interfaces can detect only the location of the touch, i.e. the device knows if and where it is being touched, but with no information about the force of the touch. However recent advances have begun to incorporate force or pressure sensitivity as a third dimension of user control. The pressure sensitive component may be incorporated directly into the touch location sensor. Alternatively, the pressure sensing component may take the form of force sensors external to the location sensing interface. This includes force sensors which are placed underneath the corners of the interface or force sensors found in an external device such as a pressure-sensitive stylus. The addition of pressure-sensitivity opens up new methods of interactivity, including pressure based text entry, menu selection and handwriting/signature recognition [1–3], and force enhanced gestures for scrolling, zooming and image manipulation [4,5].

Force or pressure-sensitive tactile sensors can already be found in applications such as robotics and electronic skin [6,7], and in biomedical applications such as bite force measurement in dentistry and human gait analysis [8,9]. Here, tactile sensing may be defined as the "detection and measurement of contact parameters in a predetermined contact area and subsequent pre-processing of the signals at the taxel level, i.e., before sending tactile data to higher levels for perceptual interpretation" [10]. These applications have been the topic of many review articles which describe the latest research and innovation [11–14].

Whilst there exist several reviews on the underlying technologies for location sensing in touch interfaces [15–20] and advances in multi-touch and 3D gesturing [21,22], to date there is no review in the literature which discusses the inclusion of pressure sensitivity into touch interfaces. The aim of this review paper is to draw together the various methods of adding pressure sensitivity to touch interfaces in HCI applications via specialised tactile sensors. First, we present a short introduction to the various methods of pressure sensing used for tactile applications, along with the advantages and disadvantages of each. Then the applications of these sensors in HCI touch interfaces are discussed in detail. The technologies have been broadly split according to application, including keyboards, laptop trackpads, and transparent touchscreens. For the latter, a distinction is made between resistive and capacitive technologies. Together, these account for 80% of the total revenue and 95% of all touchscreen units shipped in 2011 [15] and most pressure-sensing solutions are focussed here. However, the inclusion of pressure-sensing in other touchscreen technologies is also briefly discussed. A distinction is also made between pressure-sensing solutions which are incorporated directly into the touch module of the device (e.g. continuous thin films or 2D matrix arrays of sensors incorporated into the touchscreen structure) and a small number of discrete sensors placed outside of the touch module (e.g. four force sensors placed underneath the display).

2. Pressure sensing mechanisms

The most commonly used tactile or touch pressure sensors are based on resistive, capacitive, piezoelectric, inductive and optical sensing. Each of these techniques has advantages and disadvantages which are summarised in Table 1. Further information on tactile sensors can be found elsewhere in the literature, for example Yousef et al. give an excellent review of tactile sensor arrays for robotics applications, detailing the spatial resolutions of each sensor array discussed [13].

2.1. Resistive pressure sensors

2.1.1. Strain gauges and piezoresistors

A piezoresistor exhibits a change in electrical resistance with applied stress. This type of response is seen in semiconducting materials including germanium and silicon (polycrystalline or amorphous). When a stress is applied to a semiconductor resistor with initial resistance R, the change in resistance ΔR is given by

$$\Delta R = R(\pi_l \rho_l + \pi_t \rho_t) \qquad (1)$$

where π is the piezoresistive coefficient and ρ is the applied stress along the longitudinal and transverse directions, denoted by the subscripts l and t respectively. The piezoresistive coefficient is related to the change in the inter-atomic spacing when a stress is applied to the material, making it easier or harder for electrons to be promoted into the conduction band.

Piezoresistivity may also be observed in metals, although the piezoresistive coefficient is often much smaller than that of semiconductor materials. Here, the effect is mostly due to the change in geometry of a conductor under applied stress which affects the current flow through the material. Strain gauges use this effect to detect applied pressure. They have long winding conductive coils so that when the sensor is deformed through an applied pressure the cross section of the coil decreases and the conduction length increases, thus decreasing the resistance through the coil. Strain gauges typically have a higher sensitivity than piezoresistors. However piezoresistors are capable of giving a higher output per unit area and are typically smaller in the lateral dimension.